Miller and Ferry

The Measurement of the Flow of Air in Pipes By means of Circular Orifices in Thin Plates

Mechanical Engineering

B. S.

1907

UNIVERSITY
OF
ILLINOIS
LIBRARY

UNIVERSITY OF ILLINOIS
LIBRARY

Class 1907 Book M61 Volume

Je 07-10M

Digitized by the Internet Archive
in 2013

http://archive.org/details/measurementofflo00mill

THE MEASUREMENT OF THE FLOW OF AIR IN PIPES BY MEANS OF CIRCULAR ORIFICES IN THIN PLATES

BY

Alvin Charles Miller

Leroy Clark Ferry

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE

IN MECHANICAL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

OF THE

UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1907

1907
MG1

UNIVERSITY OF ILLINOIS

June 1, 1907

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

LEROY CLARK FERRY

ENTITLED MEASUREMENT OF THE FLOW OF AIR IN PIPES

BY MEANS OF CIRCULAR ORIFICES IN THIN PLATES

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering

102769

UIUC

CONTENTS

The Measurement of the Flow of Air in Pipes by means of Ciruclar Orifices in Thin Plates.

I. Previous investigation and available references.

II. Scope of the experiment.

III. Description of Apparatus and method conducting experiment.

1. Description of air compressor.
2. General description of apparatus.
3. Description of method of calibration of thermometers and pressure gauge.
4. Method of taking readings.
5. Data and results including curves.

IV. Method of computation.

1. Ideal flow.
2. Approximate acutal flow.
3. Determination of coefficient of discharge.
4. Correction of results for a temperature of 60° F.

V. Conclusion and remarks.

The Measurement of the Flow of Air in Pipes by means of Circular Orifices in Thin Plates.

1. Previous Investigation and Available References.

Up to the present time no investigations, to the writers knowledge, have been made for the purpose of determining the flow of air in pipes by means of circular orifices in thin places using high pressures and more than a slight difference of pressure on the two sides of the orifice. Consequently there is practically no available literature pertaining to this subject. The only useful reference obtainable is a paper by Mr. R.J.Durley describing his experiments on the measurement of air flowing into the atmosphere through circular orifices in thin plates and under small differences of pressure. Mr. Durley's methods were very useful as a guide in preforming this experiment and his results formed a very convenient basis to work from.

11. Scope of the Experiment.

The air compressor used has a capacity of 526 cubic feet of free air perminute to a pressure of 100 pounds per square inch. The size of the orifice was, consequently, limited to 1½ inches in diameter. The maximum pressure used was 120 pounds per square inch gauge and the greatest difference of pressure on the two sides of the orifice was 10 inches of mercury.

111. Description of Apparatus amd Methods of Conduct-

ing the Experiment.

1. The air compressor used (photo No. 1) was a two stage duplex tandem-compound machine made by the Ingersoll Sergeant Drill Co. It was designed to compress 526 cubic feet of air per minute to apressure of 100 pounds per square inch. By running the compressor above the rate speed the amount of air compressed was condiserably increased which was necessary for the larger orifices and while using a pressure of 120 pounds on the orifice the pressure in the receiver was increased to about 130 pounds .

2. The general arrangement of the apparatus may be readily seen in the photos No. 2 and 3. The receiver is about 8 feet high and 40 inches in diameter. The position of the safety valve pressure gauge and suppy pipe back next to the wall are clearly shown. The 3 inch pipe leading from the receiver at the left side has two globe valves for throttling the air in order to control the pressure on the left side of the orifice. The orifice plate was placed between two flanged castings which are shown best in photo No. 4. The plate can be seen projecting upward between the castings.

Screwed into the upper side of each casting was a special stuffing box for holding a thermometer so as to allow the bulb to come into direct contact with the air flowing through the pipe. One of these stuffing boxes is also shown in photo No. 6. A strong cord threaded through the eye at the upper end of the thermometer and securely tied

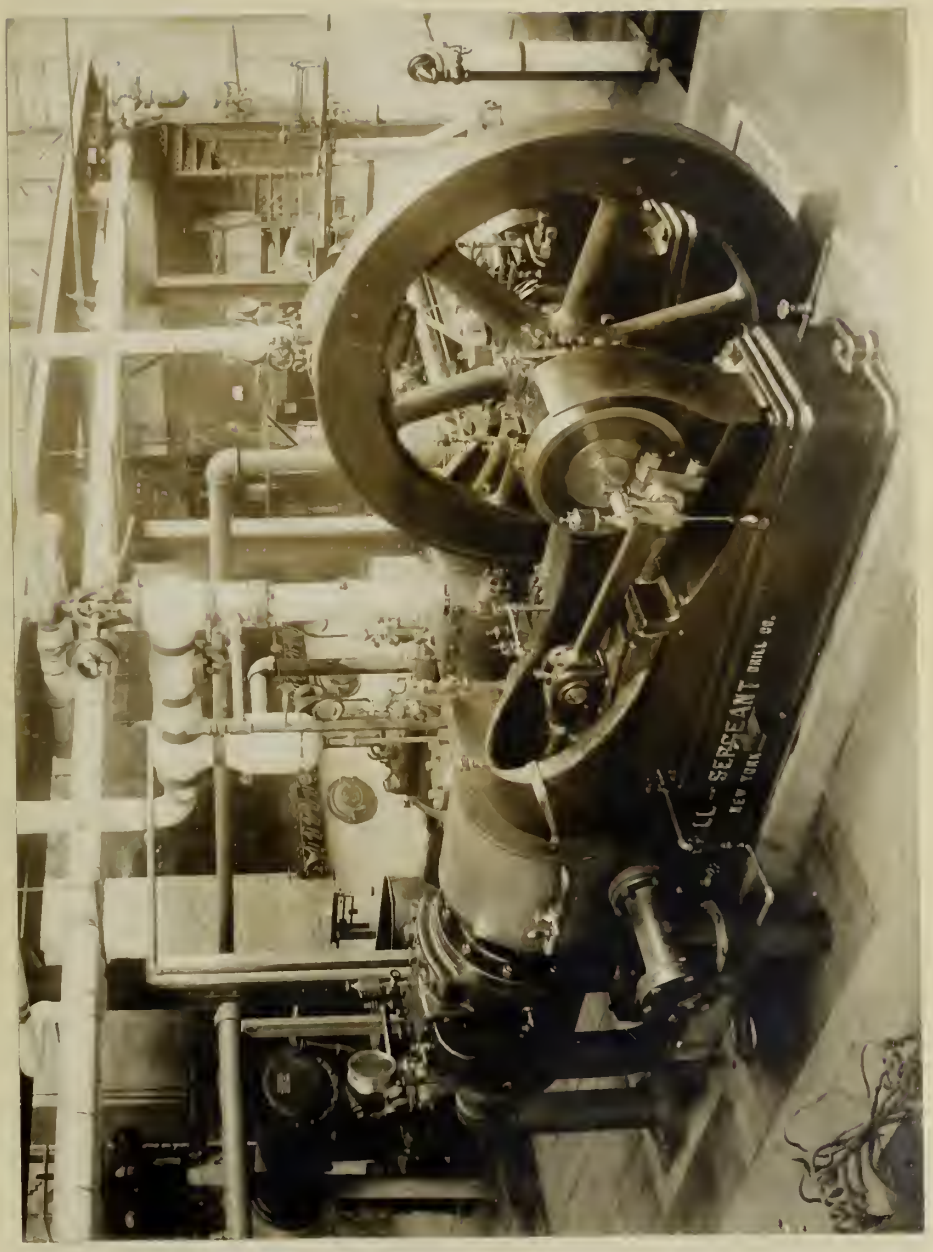


Photo No. 1

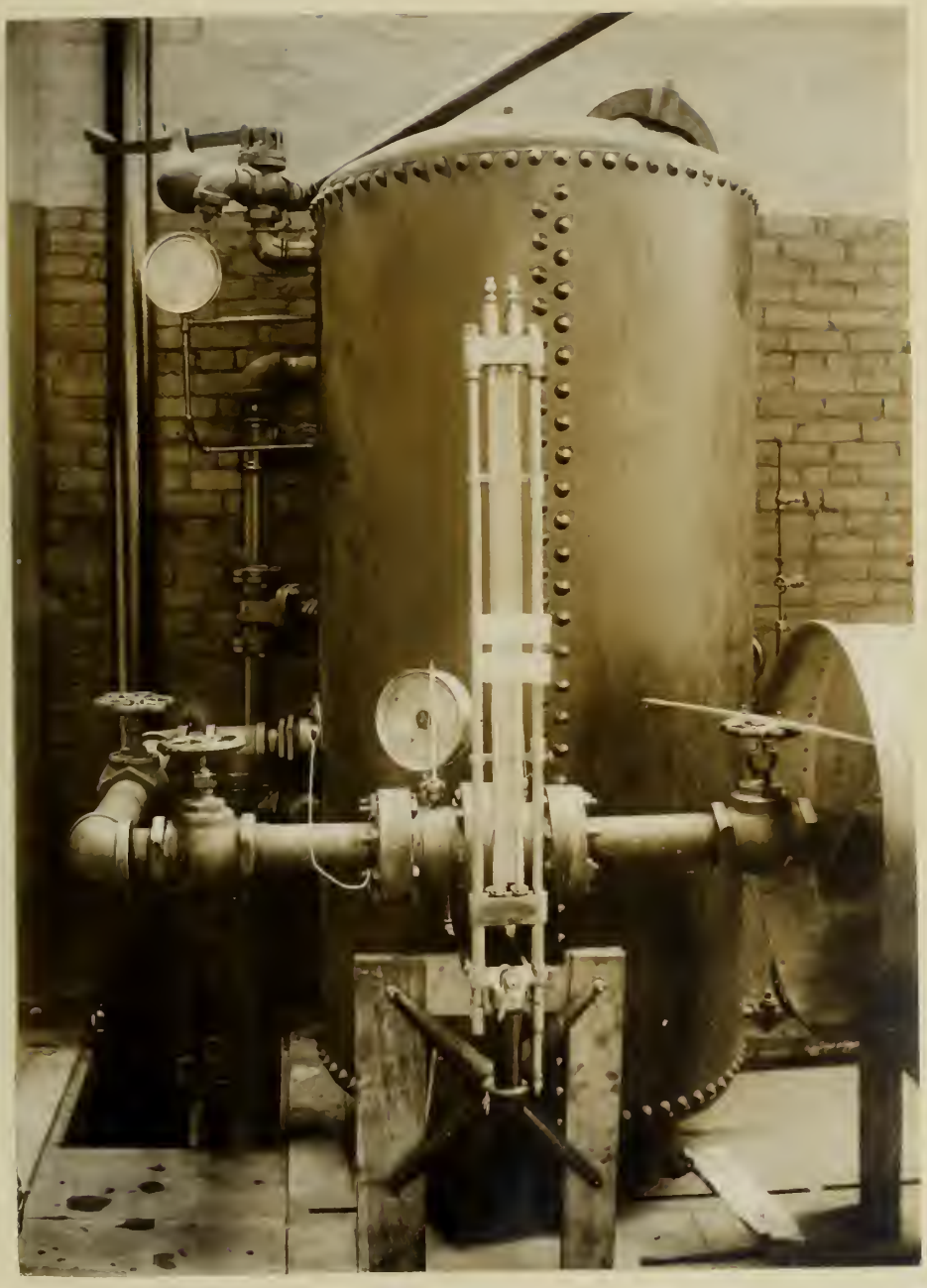


Photo No. 2.

Photo No. 3

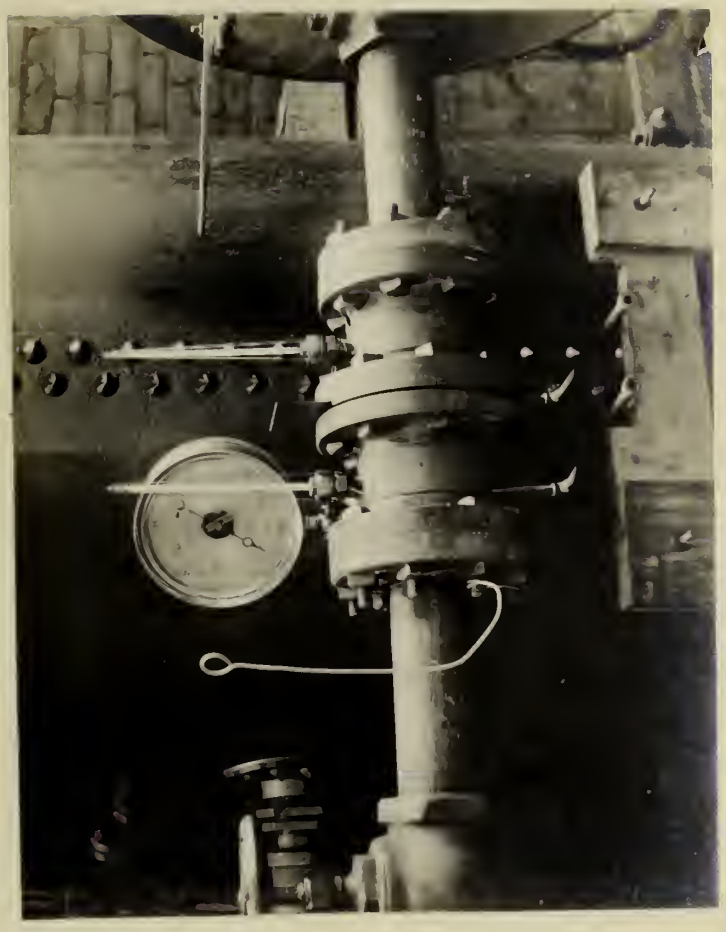


Photo No. 4

Photo No. 5

Photo No. 6

tied to the lower part of the stuffing box prevented the thermometer from blowing out when the higher pressures were used.

A carefully calibrated test gauge was connected to the left casting in order to determi e the pressure on that side of the orifice. This gauge was graduated in pounds per square inch, but could be read correctly to one-tenth of a pound. Parallax was avoided by reading the gauge while looking through a wire loop which was placed directly in line with the center of the gauge at a distance of about 14 inches.(See photo No. 4)

The difference in pressure between the two sides of the orifice was indicated by a differential mercury gauge shown in photos No. 2 and 3 . The frame of the gauge was of metal and it was carefully plumbed and rigidly secured in position. The gauge was connected to each casting near the orifice by means of one-eighth inch pipe. A union was used in each connection, the male end being filed off so as to permit the use of a gasket disc having a very small hole in the center. By the use of such a gasket fluctuation in the mercury colums was very greatly reduced enabling the reading of the position of the column to be more easily taken. The reading of the mercury columns was further facilitated byusing strips of paper, shown in photo No. 2 , which were slipped in back of the glass tubes and in front of the scale. The scale was graduated to one-tenth of an inch was wide enough so as to just fit between

the two glass tubes, and could be read to one-twentieth of an inch.

Another globe valve placed to the right of the castings was used to throttle the air on that side of the orifice thereby controling the difference in pressure between the two sides of the orifice. A stick about two feet long was bolted to the valve wheel to serve as a handle for carefully adjusting the valve, A short piece of pipe connected between this valve and an expansion tank which was about five feet long and thirty inches in diameter. The air was allowed to flow into the atmosphere from the other end of this tank through a larger orifice by means of which the quantity of the air flowing per second was determined. from the data furnished in Mr. R.J.Durley's article. The temperature of the air just before passing through the large orifice was taken by three thermometers which projected several inches inside of the tank, thus allowing the bulbs to come into direct contact with the main current of air. Each thermometer was held in place by slipping a short piece of rubber tubing over the thermometer near the upper end and pushing this rubber sleeve into a metal tube tapered on the inside and soldered into the side of the tank. Photo. No. 5 gives a good idea of the arrangement of thermometers and orifice. The low pressure in the tank was measured by means of a U tube containing water, shown in photos Nos. 3 and 5. The height of the water columns was read on a scale graduated to one-tenth of an inch, a little wider than the total width of the U

tube and could be read to one-twentieth of an inch.

3. All of the thermometers used were carefully calibrated by suspending them together with a standard thermometer in such a manner that the bulbs were about 6 or 8 inches below the surface of the water in a tank holding about 20 gallons. After the initial reading was taken steam was blown into the water until the temperature was increased about 10°. The steam was then turned off and the water brought to a uniform temperature by means of a screw agitator in the bottom of the tank. The second reading was taken then and the process repeated until the temperature of the water was about 200° . The two thermometers used in the stuffing boxes were calibrated under pressure by means of the device shown in photo No. 6. The pipe leading to the receiver was disconnected at the union just above the lower globe valve and the calibrator completely filled with water at a temperature of about 120° F. The calibrator was then connected to the air pipe. The calibration was accomplished by closing the lower globe valve, taking the thermometer reading and then turning the pressure on until the gauge registered 40 pounds and quickly taking the reading again. This was repeated for 60, 80, 100 and 120 pounds pressure . About half a dozen sets of readings were taken and the average of these used in correcting the data. Below are given the results obtained.

Gauge Pressure	Increase in Temperature.
40 lbs.	.5°
60 "	.7°
80 "	1.0°
100 "	1.4°
120 "	1.9°

The pressure gauge used on the left side of the small orifice was calibrated by means of a Crosby pressure gauge testing apparatus. Readings were taken at intervals of 5 pounds both ascending and descending.

4. The apparatus was set for taking a set of readings as follows: The globe valve nearest the receiver was closed enough to reduce the pressure to about 5 pounds above the pressure required. The two strips of paper on the mercury gauge were placed so the top edge was on the division of the scale opposite which the top of the mercury column was to come. One man then turned the globe valve to the right of the castings and watched the mercury gauge while the other man turned the globe valve to the left of the castings and watched the pressure gauge. Since the effect of changing these two valves is differentially opposite and the pressure gauge and mercury columns both change when either changes, considerable care was required to set both exactly. After the apparatus was set readings were taken of the temperature on both sides of the orifice, the height of the two water columns in the U tube and the temperature at the end of the expansion tank.

5. Data and Results including Curves.

On the following 22 pages are given the data ,results and curves of this experiment. The first 17 pages show the data and results while the remainder are curves plotted from the values obtained from the results. The data is arranged according to the size of the orifices namely: 1/8, 1/4, 1/2, 1, and 1-1/2 inches

The first column gives the number of trials, the second the diameter of the orifices, the third the difference in pressure in inches of mercury on the two sides of the orifice, the fourth the absolute pressure on the left of the orifice, the fifth the absolute temperature as the air passed through the orifice, the sixth the amount of air discharged per second, the seventh the amount of air discharged at 60° F. and the eighth the coefficient of discharge. The curves following the data were obtained by using the number of inches of mercury as abscissa and the pounds of air discharged per second at 60° F. as ordinates.

No. of Trials	Dia. of Orifice Ins.	Head ins. Hg.	Abs. Pres-sure	Abs. Temp.	Actual Discharge lbs. Sec.	Actual Discharge at 60° F.	Coef. of Discharge
1	.125	1	54.95	539.1	.00159	.00161	.522
2	"	2	55.19	539.1	.00243	.00246	.514
3	"	3	55.44	538.8	.00305	.00308	.525
4	"	4	55.69	538.6	.00356	.00360	.581
5	"	5	55.93	538.6	.00401	.00405	.584
6	"	6	56.18	538.6	.00432	.00437	.567
7	"	7	56.42	538.6	.00469	.00474	.575
8	"	8	56.67	538.6	.00505	.00510	.577
9	"	9	56.91	538.7	.00538	.00544	.578
10	"	10	56.16	539.1	.00564	.00570	.580
11	"	1	74.95	538.2	.00206	.00208	.578
12	"	2	75.19	538.9	.00291	.00294	.578
13	"	3	7544	539.2	.00379	.00384	.614
14	"	4	75.69	539.9	.00431	.00436	.604
15	"	5	75.93	540.2	.00477	.00483	.597
16	"	6	76.18	540.8	.00512	.00519	.586
17	"	7	76.42	540.8	.00567	.00575	.598
18	"	8	76.67	541.5	.00597	.00606	.589
19	"	9	76.91	541.2	.00659	.00668	.611
20	"	10	56.16	542.2	.00679	.00689	.598

Approximate Gauge Pressure

of 40 and 60 lbs.

No. of Trials	Dia. of Orifice Ins.	Head Ins. Hg.	Abs. Pressure	Abs. Temp.	Actual Discharge lbs, Sec.	Actual Discharge at 60° F.	Coef. of Discharge
21	.125	1	94.95	541.5	.00206	.00288	.563
22	"	2	95.19	541.9	.00291	.00348	.607
23	"	3	95.44	542.3	.00379	.00427	.608
24	"	4	95.69	542.6	.00431	.00503	.609
25	"	5	95.93	542.7	.00477	.00544	.598
26	"	6	96.18	542.9	.00512	.00607	.610
27	"	7	96.42	543.2	.00567	.00648	.549
28	"	8	96,67	542.9	.00597	.00689	.596
29	"	9	96.91	543.9	.00659	.00733	.598
30	"	10	97.16	544.3	.00679	.00781	.604
31	"	1	104.95	539.6	.00243	.00246	.577
32	"	2	105.19	540.0	.00344	.00348	.578
33	"	3	105.44	540.1	.00431	.00437	.584
34	"	4	105.69	540.4	.00520	.00537	.617
35	"	5	105.93	541.7	.00596	.00606	.634
36	"	6	106.18	542.6	.00632	.00643	.615
37	"	7	106.42	543.8	.00677	.00699	.617
38	"	8	106.67	543.8	.00714	.00728	.599
39	"	9	106.91	544.6	.00762	.00776	.602
40	"	10	107.16	545.8	.00800	.00815	.604

Approximate Gauge Pressure

of 80 and 90 lbs.

No. of Trials	Dia.of Orifice	Head Ins. Hg.	Abs. Pres- sure	Abs. Temp.	Actual Discharge lbs, Sec.	Actual Discharge at 60° F.	Coef. of Discharge
41	.125	1	114.95	545.4	.00258	.00263	.578
42	"	2	115.19	545.1	.00354	.00361	.587
43	"	3	115.44	546.3	.00456	.00465	.598
44	"	4	115.69	547.8	.00525	.00535	.599
45	"	5	115.93	548.4	.00594	.00606	.606
46	"	6	116.18	548.8	.00649	,00662	.605
47	"	7	116.42	549.2	.00702	.00716	.604
48	"	8	116.67	550.4	.00748	.00763	.601
49	"	9	116.91	550.9	.00798	.00814	.604
50	"	10	117.16	551.3	.00833	.00850	.594
51	"	1	124.95	549.5	.00273	.00279	.601
52	"	2	125.19	550.0	.00386	.00394	.591
53	"	3	125.44	550.0	.00471	.00481	.596
54	"	4	125.69	550.2	.00548	.00559	.600
55	"	5	125.93	550.4	.00608	.00620	.594
56	"	6	12618	550.9	.00678	.00692	.607
57	"	7	126.42	55099	.00724	.00739	.598
58	"	8	126.67	55133	.00787	.00803	.606
59	"	9	126.91	552.0	.00826	.00843	.600
60	"	10	127.16	551.7	.00872	.0089	.600

Approximate Gauge Pressure

of 100 and 110 lbs.

No. of Trials	Dia. of Orifice Ins.	Head Ins. Hg.	Abs. Pressure	Abs. Temp.	Actual Discharge lbs, sec.	Actual Discharge at 60° F.	Coef. of Discharge
61	.125	1	124.95	550.9	.00273	.00279	.578
62	"	2	125.19	551.0	.00401	.00410	.601
63	"	3	125.44	551.0	.00506	.00517	.618
64	"	4	125.69	551.1	.00569	.00581	.601
65	"	5	125.98	551.6	.00648	.00662	.611
66	"	6	126.18	552.1	.00697	.00712	.601
67	"	7	126.42	551.8	.00776	.00792	.617
68	"	8	126.67	552.1	.00810	.00827	.598
69	"	9	126.91	552.3	.00862	.00880	.603
70	"	10	127.91	552.6	.00905	.00925	.602

Approximate Gauge Pressure

of 120 lbs.

No. of Trials	Dia. of Orifice Ins.	Head Ins. Hg.	Abs. Pressure	Abs. Temp	Actual Discharge lbs, sec.	Actual Discharge at60° F.	Coef. of Discharge
1	.25	1	54.95	530.8	.00636	.00642	.525
2	"	2	55.19	530.7	.01038	.01048	.601
3	"	3	55.44	531.0	.01217	.01229	.575
4	"	4	55.69	531.5	.01469	.01485	.594
5	"	5	55.93	532.0	.01643	.01661	.596
6	"	6	56.18	532.5	.01797	.01818	.592
7	"	7	56.42	533.0	.01944	.01967	.580
8	"	8	56.67	533.5	.02079	.02105	.596
9	"	9	56.91	533.9	.02208	.02235	.592
10	"	10	57.16	534.1	.02325	.002355	.593
11	"	1	74.95	541.5	.00888	.00900	.626
12	"	2	75.19	542.0	.01212	.01228	.605
13	"	3	75.44	542.5	.01510	.01531	.613
14	"	4	75.69	543.1	.01717	.01741	.601
15	"	5	75.93	543.5	.01818	.01844	.570
16	"	6	76.18	544.0	.02137	.02168	.611
17	"	7	76.42	544.5	.02269	.02312	.589
18	"	8	76.67	545.3	.02434	.02472	.606
19	"	9	76.91	546.0	.02574	.02615	.596
20	"	10	77.16	546.6	.02705	.02750	.596

Approximate Gauge Pressure

of 40 and 60 lbs.

No. of Trials	Dia. of Orifice Ins.	Head ins. Hg.	Abs. Pres-sure	Abs. Temp.	Actual Discharge lbs,sec.	Actual Discharge at 60° F.	Coef. of Discharge
21	.25	1	94.95	547.5	.009645	.00980	.603
22	"	2	95.19	547.6	.014048	.01427	.624
23	"	3	95.44	547.5	.016823	.01709	.609
24	"	4	95.69	547.5	.018977	.01927	.593
25	"	5	95.93	547.9	.021957	.02233	.607
26	"	6	96.18	547.9	.023748	.02415	.604
27	"	7	96.42	548.0	.025803	.02628	.593
28	"	8	96.67	548.1	.027508	.02799	.611
29	"	9	96.91	548.2	.029608	.03012	.610
30	"	10	97.16	548.4	.030970	.03150	.603
31	"	1	104.95	540.5	.010338	.01047	.601
32	"	2	105.19	542.3	.014232	..01442	.601
33	"	3	105.44	543.0	.017928	.01818	.615
34	"	4	105.69	544.2	.020730	.02103	.619
35	"	5	105.93	545.1	.023224	.02357	.611
36	"	6	106.18	546.0	.025464	.02583	.618
37	"	7	106.42	547.9	.027570	.02798	.622
38	"	8	106.67	548.6	.029440	.02990	.624
39	"	9	106.91	549.9	.031225	.03174	.614
40	"	10	107.16	551.1	.032757	.03327	.610

Approximate Gauge Pressure

of 80 and 90 lbs.

No. of Trials	Dia. of Orifice Ins.	Head ins. Hg.	Abs. Pressure	Abs. Temp.	Actual Discharge lbs, sec	Actual Discharge at 60° F.	Coef. of Discharge
41	.25	1	114.95	549.5	.01096	.01228	.637
42	"	2	115.19	550.3	.01507	.01659	.610
43	"	3	115.44	550.3	.01865	.02070	.608
44	"	4	115.69	550.8	.02166	.02380	.613
45	"	5	115.93	552.3	.02432	.026380	.604
46	"	6	116.18	553.3	.02673	.02892	.601
47	"	7	116.42	553.9	.02741	.03127	.593
48	"	8	116.67	554.5	.03073	.03330	.613
49	"	9	116.91	555.1	.03248	.03570	.607
50	"	10	117.16	555.9	.03414	.03770	.613
51	"	1	124.95	554.6	.01153	.01173	.636
52	"	2	125.19	555.0	.01592	.01618	.622
53	"	3	125.44	555.3	.01932	.01965	.617
54	"	4	125.69	555.7	.02224	.02263	.617
55	"	5	125.98	555.8	.02508	.02551	.610
56	"	6	126.18	556.2	.02743	.02791	.609
57	"	7	126.42	556.6	.03003	.03060	.606
58	"	8	126.67	557.1	.03224	.03300	.627
59	"	9	126.91	557.7	.03426	.03490	.618
60	"	10	127.16	557.9	.03566	.03730	.630

Approximate Gauge Pressure

of 100 and 110 lbs.

No. of Trials	Dia. of Orifice Ins.	Head Ins. Hg.	Abs. Pres-sure	Abs. Temp.	Actual Discharge lbs,sec.	Actual Discharge at 60° F.	Coef. of Discharg
61	.25	1	134.95	556.3	.01205	.01228	.637
62	"	2	135.14	556.5	.01628	.01659	.610
63	"	3	135.44	556.6	.02032	.02070	.608
64	"	4	135.69	556.9	.02340	.02380	.613
65	"	5	135.93	557.1	.02587	.02638	.604
66	"	6	136.18	557.1	.02837	.02892	.610
67	"	7	136.42	577.2	.03067	.03127	.593
68	"	8	136.67	577.3	.03263	.03330	.613
69	"	9	136.91	577.5	.03500	.03570	.607
70	"	10	137.16	577.6	.03690	.03770	.613

Approximate Gauge Pressure

of 120 lbs.

No. of Trials	Dia. of Orifice Ins.	Head Ins. Hg.	Abs. Pressure	Abs. Temp.	Actual Discharge lbs, sec.	Actual Discharge at 60° F.	Coef. of Discharge
1	.50	1	54.95	537.7	.0299	.03015	.611
2	"	2	55.19	539.7	.0406	.04097	.588
3	"	3	55.44	550.6	.0486	.04945	.579
4	"	4	55.69	555.3	.0568	.05224	.527
5	"	5	55.93	558.2	.0634	.06480	.588
6	"	6	56.18	562.2	.0694	.07110	.583
7	"	7	56.42	565.7	.0749	.07695	.583
8	"	8	56.67	565.7	.0762	.07840	.550
9	"	9	56.91	565.5	.0816	.08399	.557
10	"	10	57.16	564.3	.0865	.08990	.561
11	"	1	74.95	557.3	.0356	.03645	.634
12	"	2	75.19	559.8	.0457	.04685	.576
13	"	3	75.44	559.9	.0560	.0575	.576
14	"	4	75.69	559.2	.0629	.06460	.561
15	"	5	75.93	559.3	.0722	.0742	.576
16	"	6	76.18	561.1	.0828	.08518	.599
17	"	7	76.42	560.5	.0865	.08898	.579
18	"	8	76.67	559.3	.0922	.09480	.576
19	"	9	76.91	560.3	.0977	.1005	.588
20	"	10	77.16	559.2	.1038	.1068	.579

Approximate Gauge Pressure

of 40 and 60 lbs.

No. of Trials	Dia. of Orifice Ins.	Head Ins. Hg.	Abs. Pres-sure	Abs. Temp.	Actual Discharge lbs. Sec.	Actual Discharge at 60° F.	Coef. of Discharge
21	.50	1	94.95	553.0	.0410	.04191	.648
22	"	2	95.19	556.0	.0542	.05542	.607
23	"	3	95.44	557.0	.0648	.06535	.584
24	"	4	95.69	558.3	.0751	.07680	.591
25	"	5	95.93	560.0	.0842	.08642	.595
26	"	6	96.18	560,7	.0912	.09365	.587
27	"	7	96.42	563.2	.1020	.1049	.607
28	"	8	96.67	565.3	.1077	.1107	.599
29	"	9	96.91	570.6	.1140	.1176	.599
30	"	10	97.16	575.4	.1180	.1222	.600
31	"	1	104.95	574.7	.0476	.0492	.723
32	"	2	105.19	575.5	.0624	.0645	.672
33	"	3	105.44	575.3	.0701	.07263	.614
34	"	4	105.69	574.8	.0809	.0839	.614
35	"	5	105.93	574.8	.0927	.0961	.624
36	"	6	106.18	575.1	.1010	.1047	.624
37	"	7	106.42	575.7	.1069	.1109	.612
38	"	8	106.67	575.2	.1143	.1186	.611
39	"	9	106.91	581.7	.1234	.1282	.621
40	"	10	107.16	584.1	.1296	.1349	.620

Approximate Gauge Pressure

of 80 and 90 lbs.

No. of Trials	Dia. of Orifice Ins,	Head Ins. Hg.	Abs. Pressure	Abs. Temp.	Actual Discharge lbs. Sec.	Actual Discharge at 60° F.	Coef. of Discharge
41	.50	1	114.95	584.9	.0753	.0784	1.10
42	"	2	115.19	584.9	.0854	.0890	.886
43	"	3	115.44	585.3	.0985	.1027	.831
44	"	4	115.69	586.8	.1238	.1292	.912
45	"	5	115.93	585.4	.1389	.1452	.912
46	"	6	116.18	585.6	.1600	.1667	.979
47	"	7	116.42	586.3	.1722	.1792	.946
48	"	8	116.67	587.5	.1838	.1966	.976
49	"	9	116.91	591.1	.2115	.2215	1.038
50	"	10	117.16	593.2	.1898	.1993	.977
51	"	1	124.95	581.5	.0748	.0769	1.035
52	"	2	125.19	583.6	.1067	.10975	1.045
53	"	3	125.44	586.9	.1308	.13500	1.046
54	"	4	125.69	591.8	.1511	.1567	1.50
55	"	5	125.93	593.7	.1320	.1373	.826
56	"	6	126.18	594.2	.1418	.1488	.813
57	"	7	126.42	594.8	.1596	.1666	.845
58	"	8	126.67	595.0	.1657	.1730	.818
59	"	9	126.91	595.1	.1772	.1851	.825
60	"	10	127.16	595.0	.1880	.1967	,830

Approximate Gauge Pressure

of 100 and 110 lbs.

No. of Trials	Dia. of Orifice Ins.	Head Ins. Hg.	Abs. Pressure	Abs. Temp.	Actual Discharge lbs. sec.	Actual Discharge at 60° F.	Coef. of Discharge
61	.50	1	134.95	594.1	.0782	.0815	1.057
62	"	2	135.14	594.1	.0846	.0881	.803
63	"	3	135.44	594.4	.1060	.1104	.825
64	"	4	135.69	596.2	.1238	.1290	.834
65	"	5	135.93	599.6	.1388	.1452	.839
66	"	6	136.18	601.2	.1460	.1526	.803
67	"	7	136.42	603.2	.1623	.1698	.828
68	"	8	136.67	604.7	.1700	.1782	.815
69	"	9	136.91	608.1	.1792	.1882	.806
70	"	10	137.16	609.1	.1869	.1964	.799

Approximate Gauge Pressure

of 120 lbs.

No. of Trials	Dia. of Orifice Ins.	Head Ins. Hg.	Abs. Pressure	Abs. Temp.	Actual Discharge lbs,sec.	Actual Discharge at 60° F.	Coef. of D Discharge
1	1.00	1	34.95	529.2	.0918	.0926	.589
2	"	2	35.19	529.8	.1297	.1308	.589
3	"	3	35.44	531.1	.1586	.1601	.585
4	"	4	35.93	532.0	.1816	.1835	.582
5	"	5	36.18	535.0	.2025	.2055	.5805
6	"	6	36.42	537.7	.2168	.2202	.566
7	"	7	36.67	541.1	.2237	.2281	.543
8	"	8	36.91	548.1	.2404	.2468	.535
9	"	9	37.16	551.2	.2518	.2580	.532
10	"	10		552.9	.2595	.2672	.524
11	"	1	44.95	554.6	.1164	.1202	.675
12	"	2	45.19	555.8	.1474	.1523	.605
13	"	3	45.44	557.2	.1762	.1821	.584
14	"	4	45.69	560.8	.2003	.2078	.583
15	"	5	45.93	563.8	.2187	.2274	.603
16	"	6	46.18	566.0	.2380	.2480	.600
17	"	7	46.42	568.2	.2560	.2674	.558
18	"	8	46.67	569.7	.2725	.2850	.555
19	"	9	46.91	571.0	.2848	.2980	546
20	"	10	47.16	572.4	.3010	.3150	.529

Approximate Gauge Pressure

of 20 and 30 lbs.

No. of Trials	Dia. of Orifice ins.	Head Ins. Hg.	Abs. Pres-sure	Abs. Temp.	Actual Discharge lbs., sec	Actual Discharge at 60° F.	Coef. of Discharge
21	1.00	1	54.95	589.0	.1273	.1333	.449
22	"	2	55.19	590.1	.1594	.1667	.600
23	"	3	55.44	590.1	.1930	.2020	.580
24	"	4	55.69	589.2	.2165	.2272	.574
25	"	5	55.93	589.2	.2426	.2545	.573
26	"	6	56.18	592.8	.2573	.2708	.555
27	"	7	56.42	594.2	.2810	.2964	.562
28	"	8	56.67	595.8	.2990	.3155	.556
29	"	9	56.91	599.5	.2960	.3130	.519
30	"	10	57.16	600.2	.3130	.3315	.521
31	"	1	64.95	561.1	.1084	.1111	.530
32	"	2	65.19	564.6	.1527	.1567	.418
33	"	3	65.44	569.9	.1865	.1925	.518
34	"	4	65.69	572.1	.2190	.2268	.528
35	"	5	65.93	575.6	.2465	.2560	.533
36	"	6	66.18	580.3	.2703	.2816	.532
37	"	7	66.42	583.6	.2925	.3057	.533
38	"	8	66.67	587.4	.3004	.3190	.520
39	"	9	66.91	593.6	.3255	.3430	.526
40	"	10	67.16	596.9	.3420	.3613	.526

Approximate Gauge Pressure

of 40 and 50 lbs.

No. of Trials	Dia. of Orifice ins.	Head Ins. Hg.	Abs. Pres-sure	Abs. Temp.	Actual Discharge lbs,sec.	Actual Discharge at 60° F	Coef. of Discharg
41	1.00	1	74.95	600.2	.1137	.1197	.522
42	"	2	75.19	598.9	.1606	.1696	.520
43	"	3	75.44	599.0	.1967	.2067	.518
44	"	4	75.69	599.9	.2304	.2440	.530
45	"	5	75.93	600.0	.2565	.2716	.525
46	"	6	76.18	601.8	.2855	.3026	.533
47	"	7	76.42	602.1	.3066	.3251	.530
48	"	8	76.67	604.0	.3282	.3490	.532
49	"	9	76.91	613.8	.3420	.3665	.526
50	"	10	77.16	615.0	.3535	.3795	.513
51	"	1	84.95	593.5	.1199	.1282	.524
52	"	2	85.19	592.1	.1701	.1812	.525
53	"	3	85.44	591.6	.2073	.2208	.520
54	"	4	85.69	592.1	.2434	.2595	.528
55	"	5	85.93	594.5	.2740	.2925	.532
56	"	6	86.18	594.9	.2952	.3155	.522
57	"	7	86.42	595.9	.3210	.3435	.525
58	"	8	86.67	596.9	.3422	.3660	.523
59	"	9	86.91	598.2	.3635	.3895	.523
60	"	10	87.16	610.2	.3790	.4102	.523

Approximate Gauge Pressure

60 and 70 lbs.

No. of Trials	Dia. of Orifice Ins.	Head Ins. Hg.	Abs. Pressure	Abs. Temp.	Actual Discharge lbs, sec.	Actual Discharge at 60° F.	Coef. of Discharg
61	1.00	1	94.95	613.2	.1342	.1433	.553
62	"	2	95.19	611.7	.1811	.1932	.529
63	"	3	95.44	611.7	.2204	.2246	.500
64	"	4	95.69	612.1	.2572	.2745	.529
65	"	5	95.93	612.7	.2862	.3060	.523
66	"	6	96.18	614.1	.3150	.3372	..528
67	"	7	96.42	616.2	.3413	.3665	.530
68	"	8	96.67	619.0	.3630	.3900	.528
69	"	9	96.91	623.0	.3850	.4135	.528.
70	"	10	97.16	625.3	.4020	.4320	.522
71	"	1	104.95	622.5	.1467	.1571	.575
72	"	2	105.19	623.1	.1983	.2125	.551
73	"	3	105.44	624.8	.2350	.2522	.534
74	"	4	105.69	627.5	.2748	.2955	.543
75	"	5	105.93	631.1	.3033	.3280	.537
76	"	6	106.18	634.8	.3293	.3573	.533
77	"	7	106.42	639.3	.3560	.3872	.543
78	"	8	106.67	643.5	.3802	.4150	.535
79	"	9	106.91	645.9	.3970	.4337	.525
80	"	20	107.16	648.1	.4165	.4560	.525
	"						

Approximate Gauge Pressure

of 80 and 90 lbs.

No. of Trials	Dia. of Orifice, Ins.	Head Ins. Hg.	Abs. Pressure	Abs. Temp.	Actual Discharge lbs. Sec.	Actual Discharge at 60° F.	Coef. of Discharge
81	1.00	1	114.95	562.2	.1532	.1568	.551
82	"	2	115.19	567.8	.2070	.2126	.525
83	"	3	115.44	572.6	.2481	.2557	.516
84	"	4	115.69	575.3	.2980	.3085	.541
85	"	5	115.93	580.8	.3245	.3375	.528
86	"	6	116.18	584.6	.3567	.3720	.535
87	"	7	116.42	591.1	.3835	.4025	.531
88	"	8	116.67	597.7	.4055	.4275	.527
90	"	1	124.95	609.0	.1415	.1502	.507
91	"	2	125.14	611.0	.2045	.2170	.518
92	"	3	125.44	612.1	.2480	.2635	.512
93	"	4	125.69	614.4	.2935	.3128	.528
94	"	5	125.95	615.2	.3290	.3515	.528
95	"	6	126.18	618.4	.3622	.3870	.529
100	"	1	134.95	617.5	.1528	.1623	.513
101	"	2	135.14	620.3	.2118	.2266	.521
102	"	3	135.44	620.4	.2570	.2755	.515
103	"	4	135.69	621.4	.3030	.3250	.525
104	"	55	135.98	623.1	.3410	.3664	.529

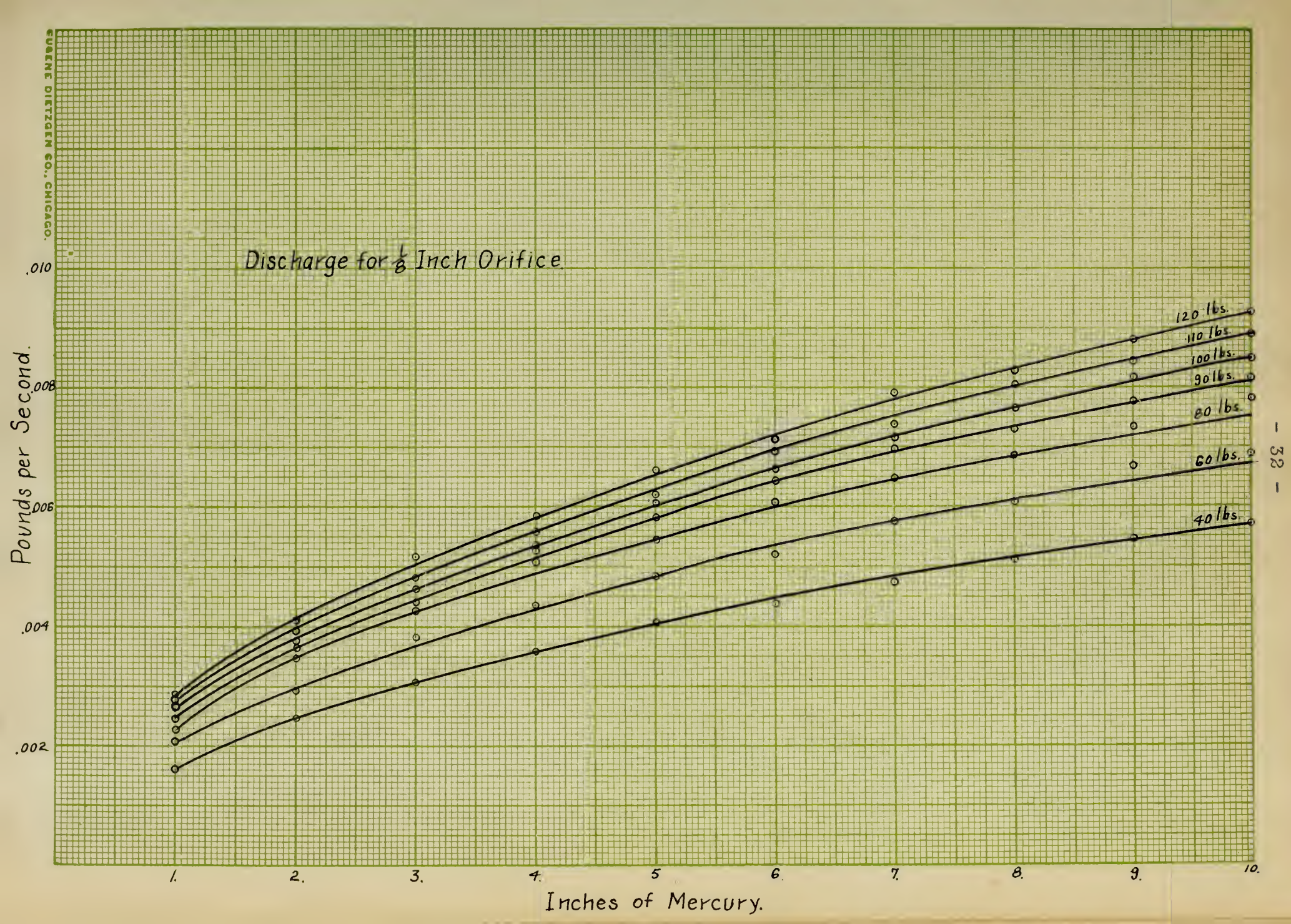
Approximate Gauge Pressure

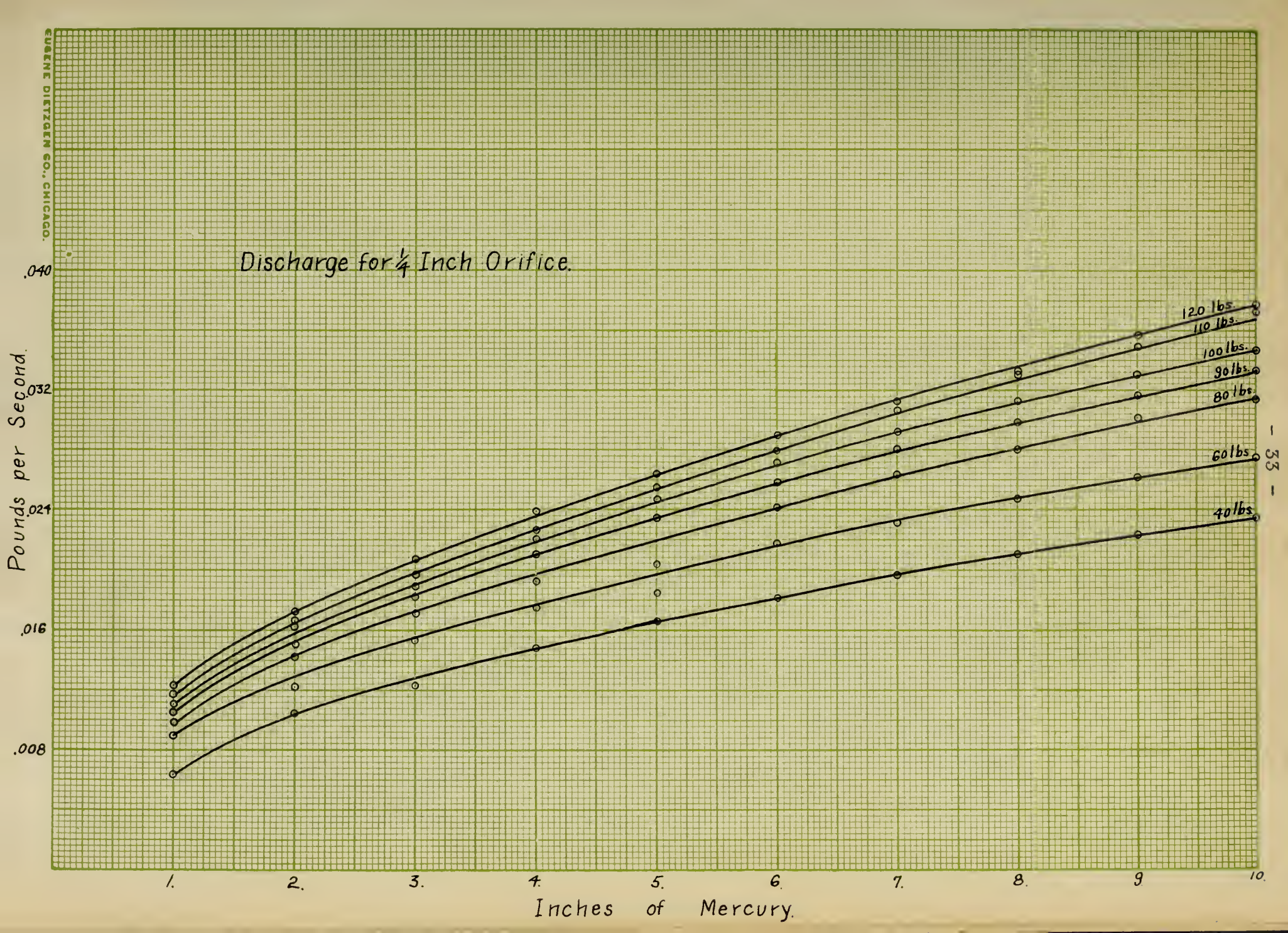
of 100 - 110 - 120 lbs.

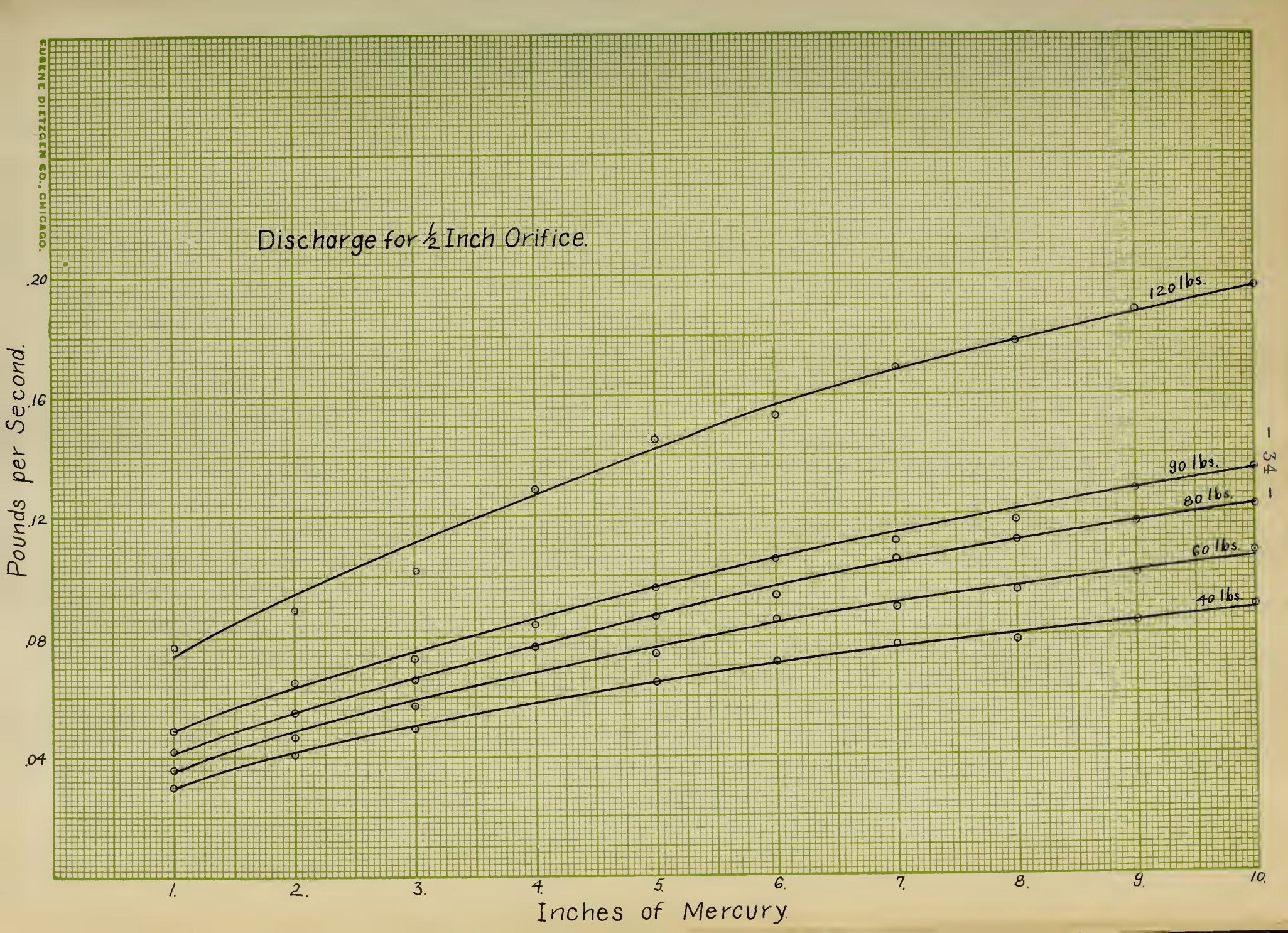
No. of Trials	Dia. of Orifice ins.	Head Ins. Hg.	Abs Pressure	Abs. Temp.	Actual Discharge lbs. sec.	Actual Discharge at 60° F,	Coef. of Discharge
1	1.5	1	34.95	543.1	.1678	.1695	.480
2	"	2	35.19	551.4	.2747	.2788	.558
3	"	3	35.44	560.6	.3390	.3472	.564
4	"	4	35,69	569.0	.37500	.3870	.554
5	"	5	35.93	575.2	.4130	.4290	.535
6	"	6	36.18	582.0	.3972	.4160	.472
7	"	7	36.42	584.9	.4325	.4560	.478
8	"	8	36.67	588.3	.4505	.4764	.464
9	"	9	36.91	589.0	.4875	.5105	.468
10	"	10	37.16	589.2	.5075	.5370	.486
11	"	1	44.95	594.7	.1970	.2080	.519
12	"	2	45.19	589.8	.2745	.2895	.510
13	"	3	45.44	589.7	.3303	.34833	.499
14	"	4	45.69	588.6	.3773	.3982	.493
15	"	5	45.93	591.7	.4200	.4440	.490
16	"	6	46.18	593.2	.4630	.4905	.493
17	"	7	46.42	592.4	.4950	.5250	.487
18	"	8	46.67	589.6	.5391	.5620	.487
19	"	9	46.91	587.7	.5592	.5910	.481
20	"	10	47.16	589.1	.5960	.6280	.482

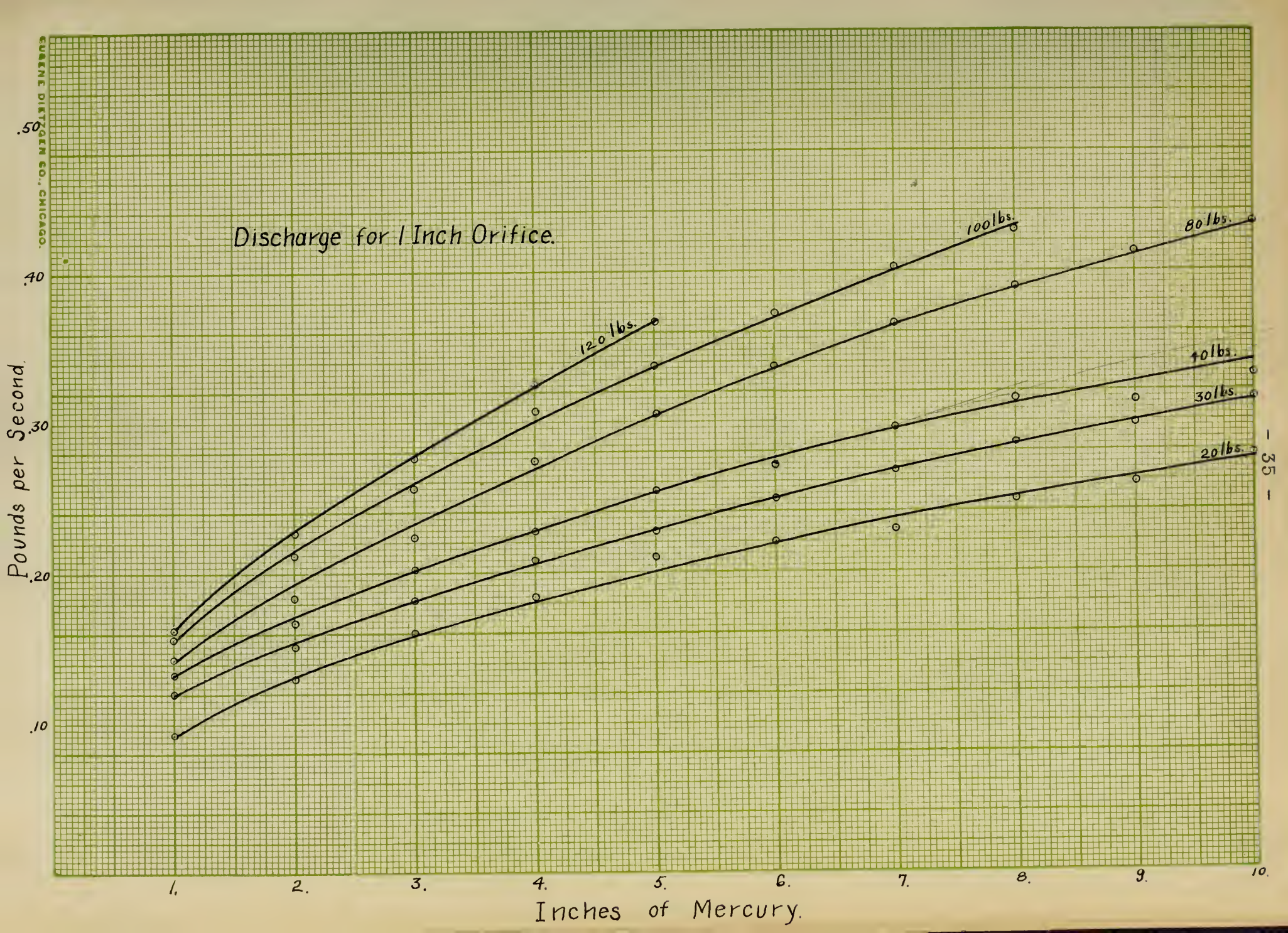
Approximate Gauge Pressure

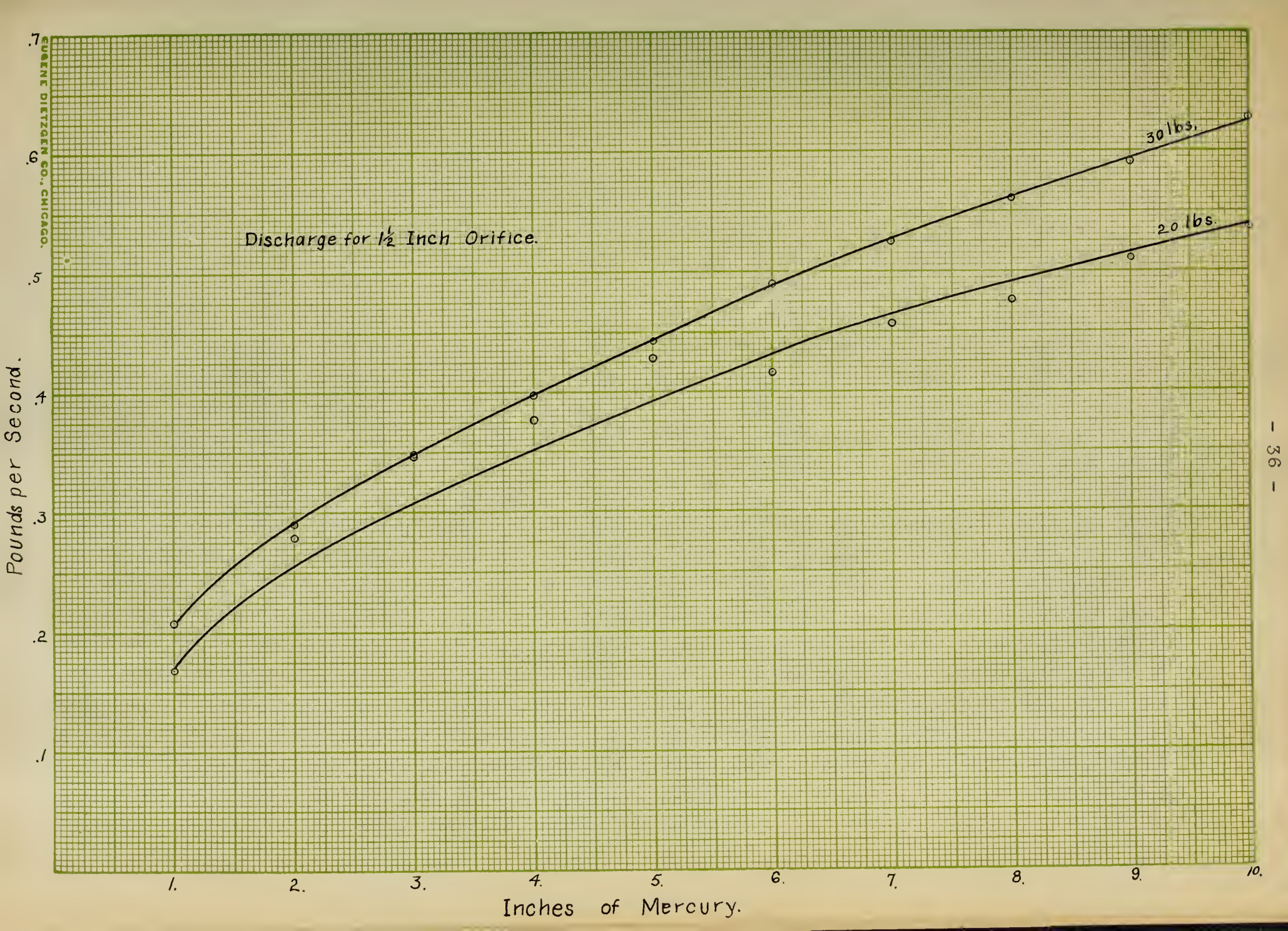
of 20 and 30 lbs.


EUGENE DIETZGEN CO., CHICAGO.
Discharge for 1/8 Inch Orifice.
Pounds per Second.
.010
.008
.006
.004
.002
120 lbs.
110 lbs.
100 lbs.
90 lbs.
80 lbs.
60 lbs.
40 lbs.
1.
2.
3.
4.
5
6.
7.
8.
9.
10.
Inches of Mercury.


EUGENE DIETZGEN CO., CHICAGO.
Discharge for ¼ Inch Orifice.
Pounds per Second.
.040
.032
.024
.016
.008
120 lbs.
110 lbs.
100 lbs.
90 lbs.
80 lbs.
60 lbs.
40 lbs.
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
Inches of Mercury.
- 33 -


EUGENE DIETZGEN CO., CHICAGO.
Discharge for ½ Inch Orifice.
Pounds per Second.
.20
.16
.12
.08
.04
120 lbs.
90 lbs.
80 lbs.
60 lbs.
40 lbs.
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
Inches of Mercury.


EUGENE DIETZGEN CO., CHICAGO.
Discharge for 1 Inch Orifice.
100 lbs.
80 lbs.
120 lbs.
40 lbs.
30 lbs.
20 lbs.
.50
.40
.30
.20
.10
Pounds per Second.
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
Inches of Mercury.


EUGENE DIETZGEN CO., CHICAGO.
Discharge for 1½ Inch Orifice.
30 lbs.
20 lbs.
Pounds per Second.
.7
.6
.5
.4
.3
.2
.1
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
Inches of Mercury.

IV. Methods of Computation.

1. The formula for computing the adiabatic flow of a perfect gas through a frictionless orifice taken from "Peabody's Thermodynamics" page 132 as explained in Mr. Durley's paper is

$$W = A\sqrt{2g\frac{\gamma}{\gamma-1}\cdot\frac{P_1}{V_1}\left[\left(\frac{P_2}{P_1}\right)^{\frac{2}{\gamma}} - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{2}}\right]} \quad \text{----- (1)}$$

In this expression.

W = weight of gas discharged per second in pounds.

A = Area of cross section of jet in square feet.

P_1 = Pressure inside orifice in pounds per square foot.

P_2 = Pressure outside orifice.

V_1 = Specific volume of gas inside orifice in cubic feet per pound.

γ = Ratio $\frac{K_p}{K_v}$ = $\frac{\text{specific heat at constant pressure}}{\text{specific heat at constant volume}}$ per lb.

Since γ = 1.404 for air, we have from equation (1) for a circular orifice of diameter of d inches, the initial temperature of the air being 60 degress Fahr. (or 521 degrees abs.)

$$W = 0.00816\, d^2\sqrt{\frac{P_1}{V_1}\left[\left(\frac{P_2}{P_1}\right)^{1.425} - \left(\frac{P_2}{P_1}\right)^{1.712}\right]}$$

$$W = 0.000491\, d^2 P_1\sqrt{\left(\frac{P_2}{P_1}\right)^{1.425} - \left(\frac{P_2}{P_1}\right)^{1.712}} \quad (2)$$

if we measure P in lbs. per square inch,

$$W = 0.07058\, d^2 P\sqrt{\left(\frac{P_2}{P_1}\right)^{1.425} - \left(\frac{P_2}{P_1}\right)^{1.712}} \quad \text{------ (2a)}$$

"In practise the flow is not frictionless, nor is it perfectly adiabatic , and the amount of heat entering or leaving the gas is not known. Hence ,the weight actually discharged is to be found from such a formula as (2) by introducing a coefficient of discharge (generally less than unity) depending on the conditions of the experiment and on the construction of the particular form of orifice employed."

2. The above formula is not very convenient for calculation and for practical purposes it is better(if the ratio $\frac{P_2}{P_1}$ is nearly unity) to employ a somewhat similar expression, obtained by assuming that the air or gas flows as would a liquid of the same mean density. In other words, we neglect the charges of density and temperature occuing as the air passes through the orifice, and are thus able to obtain a simpler though approximate formula as follows:

Let i = difference of pressure (between P_1 and P_2) measured in inches of mercury.

T = mean absolute temperature of air(supposed to remain unchanged).

u = velocity of air in feet per second (supposed uniform over whole cross section of orifice).

V = Specific volume of air (supposed constant during passage through orifice.

P = mean pressure of air in pounds per square foot.

Then the head (measured in feet of air) under which the

flow takes place is $h = V (P_1 - P_2)$.

But a pressure of one inch mercury = 70.72 pounds per square foot, so that $h = 70.72\ i\ V$

Now $u^2 = 2gh$ and the weight discharged per square foot of orifice per second will be

$$\frac{u}{V} = \sqrt{\frac{2g \times 70.72\ i\ V}{V}} = \sqrt{\frac{64.4 \times 70.72\ i}{V}}$$

But $V = \frac{53.18\ T}{P}$ for air, so the ideal discharge per square foot of orifice per second will be

$$\sqrt{\frac{64.4 \times 70.72\ i\ P}{53.18\ T}} = 9.25 \sqrt{\frac{i\ P}{T}} \text{ pounds}$$

For an orifice of diameter d inches the ideal discharge will be

$$W = \frac{0.7854 d^2}{144} \times 9.25 \sqrt{\frac{iP}{T}} = 0.05045\ d^2 \sqrt{\frac{i\ P}{T}}$$

Since the pressure is read in pounds per square inch from the pressure gauge it is more convenient to modify the above formula by replacing $\frac{14}{P}$ by p = pounds pressure per square inch, then the actual discharge will be

$$W = 0.06062\ d^2 \sqrt{\frac{i\ p}{T}} \times C$$

The coefficient of discharge C was found for each set of readings by making the above computation and equating the result to the discharge of the larger orifice , in the expansion tank, as computed from the formula given in Mr. Durley's papers. This formula which was derived in the same manner is as the above, is

$$W = 0.6299\ d^2 \sqrt{\frac{i}{T}} \times C$$

in which i = difference of pressure measured in inches of

water. The values of c are given in the following tables which are taken from Mr. Durley's paper.

Coefficents of Discharge for Various Heads and Dia. of Orific

Dia. of Orifice in.	1-inch Head	2- inch Head	3-inch Head	4- inch Head	5 - inch Head
5-16	0.603	0.606	0.610	0.613	0.616
1-2	0.602	0.605	0.608	0.610	0.613
1	0.601	0.603	0.605	0.606	0.607
1.5	0.601	0.601	0.602	0.603	0.603
2	0.600	0.600	0.600	0.600	0.600
2.5	0.599	0.599	0.599	0.598	0.598
3	0.599	0.598	0.597	0.596	0.596
3.5	0.599	0.597	0.596	0.595	0.594
4	0.598	0.597	0.595	0.594	0.593
4.5	0.598	0.596	0.594	0.593	0.592

As the temperature of the air continually changed duing each part of the experimnet, it was necessary before equating the discharge as computed by the two fromulas above, to reduce both results to values corresponding to a temperature of 60 degrees Fahr.(or 521 degrees absolute) as follows:

Let W = Computed discharge for temperature T

Wc= Corrected discharge for temperaure of 60 degrees Fahr.

Since the discharge varies inversely as the square root of the absolute temperature, the corrected discharge will be

$$Wc = \frac{\quad}{\sqrt{521}}$$

V. Conclusions and Remarks

From the experiments and curves, it seems that:

The coefficient of discharge increases as the diameter of the orifice increases .

The coefficient of discharge increases as the pressure used increases for the one-eighth, one-fourth and one-half inch orifice, but remains practically uniform for the one inch and one and one-half inch.

The coefficient of discharge remains practically constant with the different heads on the orifices.

The wide and frequently uniniform variation in the values of the amount of flow is probably due , at least partly to insufficient accurate reading of the height of the water columns in the U tube, a more accurate device for measuring the height of the columns would be a V tube with an angle of about 120° between the two sides,. Another source of error, perhaps much greater is the use of the larger orifices in the end of a tank 30 inches in diameter. In this experiment it was assumed that the results concerning the velocity of approach in Mr. Durley's test were correct, but the great variations in the amount of the calculated discharge of air, each time the orifices at the end of the tank were changed, seem to indicate that his results were effected to a greater extent than he supposed by the velocity of approach, especially for orifices of the larger

sizes. This error seems more apparent when orifices 2 inches in diameter and larger were used. The variations in amount of discharge when the crifices were changed are cited and can readily be seen in the following places: Under data and results for one-half inch orifice between trials 7-8, 45-46, 49-50, and 54-55. Under 1 inch crifice between trials 6-7 and 28- 29. Under 1.5 inch orifice between trial 5 - 6. The one-eighth inch and one-fourth inch orifices did not necessitate a change of the orifice discharging from the end of the tank and consequently they gave results with very much less variation in the amount of discharge.

Owing to the lack of time, for investigation the results obtained in this experiment are not as accurate as we should liked to have had them or as they might have been had the time not been so limited. The results may not be accurate enough to be of much value,however, it is hoped that future investigators of this subject may find herein a few suggestions and methods by which the amount of flow under higher pressure can be measured.

UNIVERSITY OF ILLINOIS-URBANA
3 0112 082195725